ORAU Team NIOSH Dose Reconstruction Project Technical Basis Document for the Paducah Gaseous Diffusion Plant – Occupational Environmental Dose	Document Number: ORAUT-TKBS-0019-4 Effective Date: 08/24/2004 Revision No.: 00 Controlled Copy No.: _______ Page 1 of 22
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ACRONYMS AND ABBREVIATIONS

Bq	becquerel
CEDE	committed effective dose equivalent
cfm	cubic feet per minute
cm	centimeter
cpm	counts per minute
DOE	U.S. Department of Energy
ft	foot
GM	Geiger-Muller
hr	hour
m	meter
mg	milligram
mR	milliroentgen
mrem	millirem
PGDP	Paducah Gaseous Diffusion Plant
s	second
TBD	technical basis document
TLD	thermoluminescent dosimeter
TRU	transuranics
U.S.C.	United States Code
yr	year

4.1 INTRODUCTION

Technical Basis Documents (TBDs) and Site Profile Documents are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist the National Institute for Occupational Safety and Health in the completion of the individual work required for each dose reconstruction.

In this document the word “facility” is used as a general term for an area, building or group of buildings that served a specific purpose at a site. It does not necessarily connote an “atomic weapons employer facility” or a “Department of Energy facility” as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [42 U.S.C. Section 7384l (5) and (12)].

This Paducah Gaseous Diffusion Plant (PGDP) TBD describes the potential exposures from ambient sources while working outside the process buildings. Section 4.2 discusses internal dose from the breathing of airborne concentrations of radionuclides released while on the PGDP site. Section 4.3 describes potential external dose from sources of radiation outside process buildings. Section 4.4 discusses possible sources of uncertainty associated with both of these sources of environmental dose.

At PGDP all personnel wore film badges under a 1962 procedure (Union Carbide 1962a). This policy was actually practiced before the 1962 procedure, as evidenced by the large increase in the number of monitored personnel in 1960. Because the practice was to wear dosimetry at all times while on the site, the dose reconstructor must consider if the dosimetry records already account for the external environmental dose. To provide the basis for estimating the environmental dose for years when monitoring was not performed or was not sufficient to apply coworker data, this TBD provides annual intakes and ambient external dose for every year from 1953 to 2001 (2001 is the last year with publicly available data).

4.2 INTERNAL DOSE FROM ONSITE ATMOSPHERIC RADIONUCLIDE CONCENTRATION

4.2.1 Preoperational Background Survey

The Carbide and Chemicals Company analyzed samples for airborne uranium in August 1952 to document the preoperational conditions at PGDP (CCC 1953). Ten chemically processed samples showed 0.00 mg/m^3 uranium in the air. Two samples analyzed for alpha activity had results of 0.00 and 0.018 cpm/ft^3 (approximately 0.01 Bq/m^3). However, what is known about the collection process and analysis of samples indicates that these results are not sufficient to conclude that there was no preexisting airborne radioactivity in the area. As sampling and analysis techniques improved over the years, the presence of measurable sources from sources other than PGDP became evident (such as fallout from atomic weapons testing and flyash from nearby fossil-fueled power stations).

4.2.2 Ambient Air Sample Collection Network

By 1958 (Union Carbide 1959), PGDP had established a network of permanent stations on and off the site to collect continuous ambient air samples. Sampling data are available in annual environmental reports published since 1958 for four perimeter locations (inside the fence) and varying numbers of offsite locations.

The 1959 Environmental Monitoring Report (Union Carbide 1960) describes the outdoor air sampling:

> *The outdoor air samples for alpha and beta active particulates were collected approximately every eight days at the same locations as the fluoride samples. They were 24-hour samples and were collected on Whatman number 40 filter paper at a flow rate of 0.5 cubic feet per minute. These samples were counted for alpha activity on parallel plate counters equipped with amplifiers and scalers and were counted for beta activity with Geiger-Muller tubes equipped with scalers.*

An Air Sampling Procedure dated September 1962, describes the environmental air sampling (Union Carbide 1962b):

> *The samples are collected by a 110 volt Gast pump using membrane filter type AM-4 2 in. at a flow rate of 0.3 cfm (11 cm/s). Samples are continuous and of week-long duration.*

The environmental report for 1960 (Union Carbide 1961) indicates that the change in monitoring techniques occurred about mid-1960.

The principal purpose of the ambient air monitoring network was to assess if air emissions from PGDP affected the air quality in the surrounding area. This would demonstrate compliance with U.S. Department of Energy (DOE) Derived Concentration Guidelines or U.S. Environmental Protection Agency, State of Kentucky, and (as of 1997) U.S. Nuclear Regulatory Commission regulations for airborne releases to the public around PGDP. Therefore, the majority of the monitoring stations are off the site or just inside the security fence. There have been a limited number of onsite monitoring stations, but reports from these stations are not available. Therefore, in the calculation of worker intake, this TBD considers only those results from ambient air monitoring locations adjacent to or outside the PGDP security fence. Table 4-1 lists these monitors and their locations. Union Carbide (1960) and DOE (1989, 1996) contain maps showing the old and new naming conventions.

Table 4-1. Ambient air sampling stations.

Designation	Location	Direction from center of plant
PN-6	At security fence between C-535 and C-537	North
PE-8	At security fence near McCaw Road	East
PS-2	At security fence approximately 300 meters south of C-100	South
PW-5	At security fence near C-749	West
IN	Offsite about 2 km north of PN	North
IE	Offsite about 1 km east-northeast of PE	East
ISE	Offsite about 2 km southeast of PS	Southeast
IS	Offsite approx 1.5 km south-southwest of PS	South
IW	Offsite approx 1.2 km west-northwest of PW	West
BN	At the north boundary of property, 0.3 km north of PN	North

Several changes to the sampling program occurred, primarily involving sample technique and equipment. From 1958 to 1993, low-volume samplers were the principal samplers, with multiple filter types and flow rates.

The general practice for air samples was to perform gross alpha and beta-gamma counts. The activity of gross alpha was associated with the release of uranium, while beta-gamma activity was associated with the release of ^{99}Tc. Overall, the alpha activity was about 7% of the beta activity in air samples. No air samples taken adjacent to the security fence or outside the security fence have exceeded applicable limits to the public.

There have been releases of radionuclides to the atmosphere since the beginning of operations, including accidental releases. PGDP release data have been estimated or recorded since operations began in 1953. The uncertainty in the amounts released and lack of a complete ambient air-monitoring network for the first 6 yr of operation are technical issues that the occupational dose reconstruction must address. Therefore, Section 4.2.3 discusses a method to estimate potential radionuclide air concentrations for 1953 to 1958 and to account for potential uncertainty in the release data.

There are several points of airborne release. These include the stacks for buildings C-310, C-340, C-400 and C-410. The first two stacks are on the east side of the plant, while the remaining release points are near the center of the plant. General plant ventilation exhausts released lesser concentrations over large areas of the building roofs. The many sources of airborne releases, use of stacks, and the nearly constant wind contribute to a very effective diffusion of contaminants over the small site with no significant terrain features to channel or moderate the wind. Figure 4-1 shows a wind rose from the 1993 annual environmental report for PGDP, which shows wind blowing predominantly into the southeasterly direction (DOE 1994, Figure 5.1).

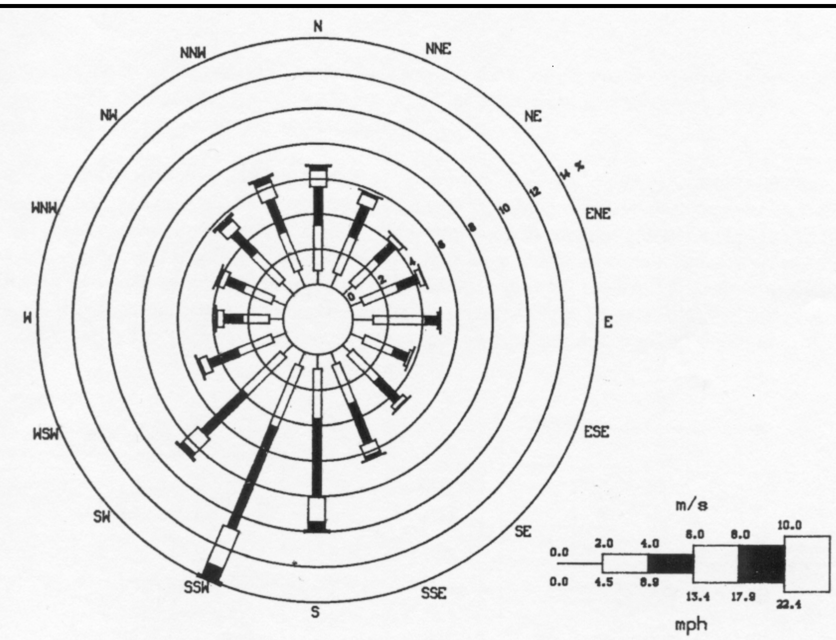

Figure 5.1 Wind Rose (60-m level) showing the wind speed frequency distribution data for 1989 to 1993.

Figure 4-1. Wind rose from 1993 environmental report.

4.2.3 Methodology

The estimation of airborne concentrations at specific locations around the PGDP site using traditional transport modeling approaches is limited by several factors:

- The numerous release points, which include stacks, vents, and other emission sources
- The characteristics of the release points
- The limited number of air-sampling locations

- The relatively short distances between the release points and the onsite receptor locations
- The density and configurations of buildings at the site

Past estimates of doses to members of the public off the site indicate that the potential internal dose from airborne releases to PGDP workers should be relatively low, about 10 mrem committed effective dose equivalent (CEDE) or less. Air data from nearby locations and at the security fence are consistent from location to location, yet dependent on year with fallout from weapons testing dominating the results through the early 1960s. This collection of data provides reasonable approximation of general airborne radioactivity and establishment of trends as a function of time.

Factors other than transport and release rates from PGDP influence the gradual reduction in the air concentration over the 50-yr history of PGDP. The records show that releases fell by 5 orders of magnitude while concentrations decreased by less than 3 orders of magnitude. These factors include:

- Improved monitoring methods reduced the minimum detectable concentrations.

- Concentrations of naturally occurring radioactive material released from a nearby fossil-fuel electric plant fell over the years because of improved environmental controls. (Figure 4-4 in Section 4.3.1 shows the proximity of the electric plant.

- The effect of atmospheric weapons testing and the radioactive decay of fallout (air-monitoring results correspond more with fallout than with plant releases).

The methodology for the intake from onsite atmospheric radionuclide concentrations applies directly to available air-sampling data. The maximum site measurement for gross alpha and gross beta-gamma should be applied for all workers throughout the site. Air-sampling measurement error and uncertainty should be accounted for by use of the maximum value reported for the year at any location. Available data are limited to annual averages for each location; the limited amount of data does not support statistical analysis.

4.2.4 Estimation of Ambient Airborne Radionuclide Concentrations

In years for which air concentration data are unavailable, release data and maximum air concentration data for adjacent years were evaluated to generate estimates of the air concentration. The alpha concentrations chosen were based on the higher value indicated by releases (1952 to 1956) or by air monitoring trends (1990 and 1994). Similarly, the beta concentrations were chosen to be proportional to releases (1952 to 1958 and 1989) and for the later years (1993 and 1995 to 2001) as an approximate average of the preceding 10 measurements, which results in higher estimates than the downward trend.

Figures 4-2 and 4-3 show these data, and demonstrate that chosen values are reasonable and will not underestimate dose. These graphs, one for alpha and one for beta, show release values for each year available, measured airborne concentrations, and estimates of assigned values for airborne concentrations if actual measurements were not available.

4.2.5 Data for Ambient Airborne Radionuclide Concentrations and Annual Airborne Releases

This TBD relied on several data sources for estimating ambient airborne radionuclide concentrations and for annual airborne releases by radionuclide. The principal sources were the annual

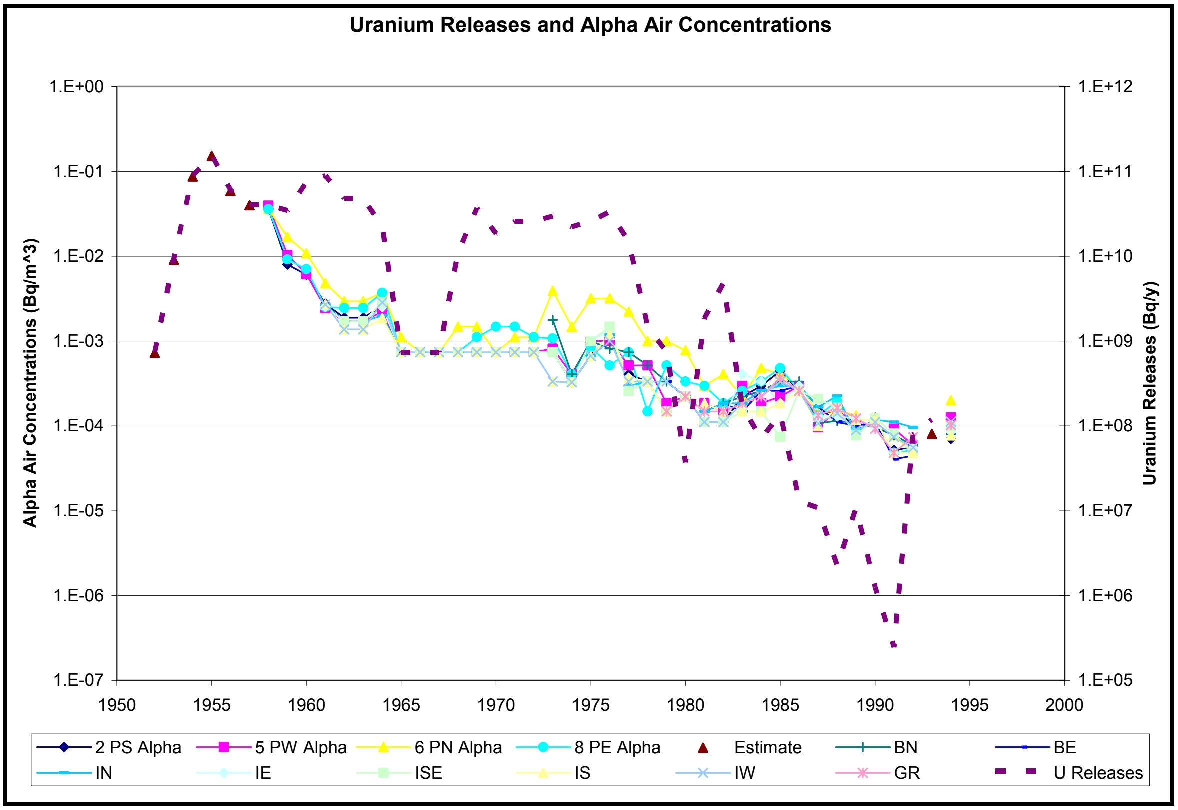

Figure 4-2. Alpha air concentrations.

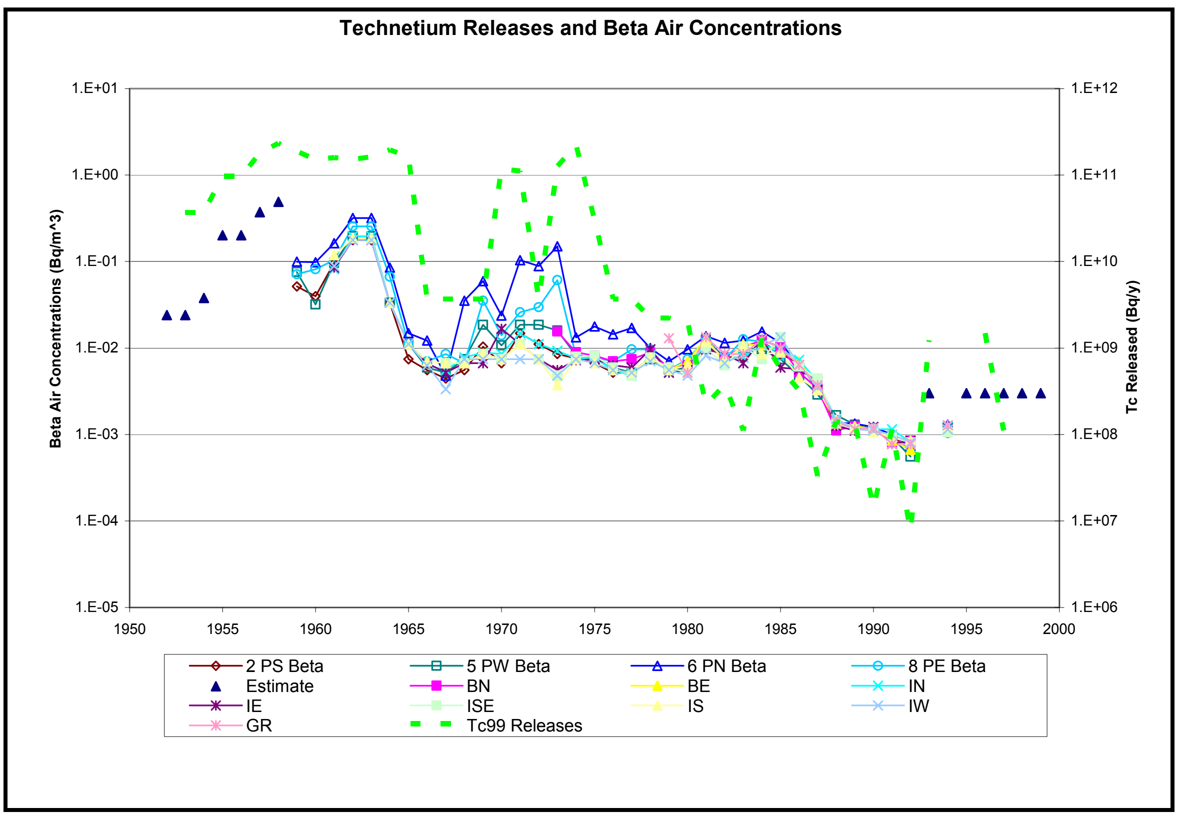

Figure 4-3. Beta air concentrations.

environmental reports for PGDP from 1958 and through 2001 (see the reference list at the end of this document). Measurements from the air-monitoring locations listed in Tables 4-2 and 4-3 were collected from these documents and applied using the method described. Attachment 4A provides an expanded version of this data, including additional background monitoring points. If data were not provided or additional information was required, these documents were supplemented by information provided by DOE, Bechtel-Jacobs (the current DOE environmental restoration contractor at PGDP), or the United States Enrichment Corporation.

4.2.6 Estimation of Annual Intake from Airborne Radionuclides

Using the maximum airborne radionuclide concentration in a year (either from actual data or an estimated value), annual intakes for the radionuclides of concern were derived by using an assumed annual respiration rate of 2,400 m^3/yr. Most years have only a potential for contributing only about 1 mrem CEDE or less. Intakes from inhalation are potentially significant only for operations before 1963.

Transuranics (TRU) were introduced to the facility with recycled uranium feed material. There were areas in the buildings that contributed to intake, mainly around the ash from the fluorination process and the cylinder heals. There were no reports of TRU in the environmental air sampling. To determine the risk from TRU, an analysis was performed to determine the relative intake of TRU to uranium. The analysis determined that the doses from TRU intake outside the buildings does not contribute enough dose to be significant, less than 0.2% of dose and 0.06% of intake.

4.3 EXTERNAL DOSE

During the first decade of operation, a limited number of workers were monitored for external exposure. There was a marked increase in the number of workers monitored in 1960. By 1962, procedures required employees to be monitored by film badge (Union Carbide 1962a). Data were entered on IBM punch cards and reports went to Health Physics personnel, who distributed data to the individual departments. The cards were maintained by Plant Records and an annual report for each employee was prepared and included in the individual’s file in Medical Records.

Workers receive external dose from ambient radiation levels. Until September 1981, external gamma radiation levels were measured with a calibrated Geiger-Muller (GM) counter 3 ft above the ground. The limit of sensitivity for the GM tube was 1.0×10^{-4} mR/hr (the basis for energy calibration is not known). The frequency of the GM exposure rate surveys varied; sometimes they were weekly and sometimes they were monthly.

From 1981 to the present, thermoluminescent dosimeters (TLDs) have been used to determine ambient radiation levels. TLD readings are considered more accurate than GM measurements because the GM counter takes more discrete readings and could miss fluctuations in gamma levels. TLD locations include those previously monitored by GM counters. TLDs offer greater sensitivity and represent an integration of data rather than the discrete results associated with a GM counter. Information is not available on the environmental TLD detection limit.

Over the years various combinations of TLD chip configurations and monitoring locations were used. It is clear from security fence data that external exposure rates increased over the life of the site. Two factors contributed to this trend: The improved monitoring of the newer TLDs and, more significantly, the increasing inventory of depleted uranium cylinders. The highest security fence observation was 194 mrem deep dose equivalent for 2,000 hr. This occurred in 2001, the most recent year during which results were from the modern monitoring techniques.

Table 4-2. Uranium releases, alpha airborne concentrations, and intakes.

Year	Uranium release (Bq/yr)	Outdoor alpha concentrations (Bq/m^3) at certain monitoring locations							Annual uranium intake (Bq/yr)
		2 PS alpha	5 PW alpha	6 PN alpha	8 PE alpha	Estimate for missing years	Maximum reported	Applied concentration	
1952	7.4E+08					7.3E-04		7.3E-04	1.7E+00
1953	9.3E+09					9.1E-03		9.1E-03	2.2E+01
1954	8.9E+10					8.7E-02		8.7E-02	2.1E+02
1955	1.6E+11					1.5E-01		1.5E-01	3.7E+02
1956	6.0E+10					5.9E-02		5.9E-02	1.4E+02
1957	4.1E+10					4.0E-02		4.0E-02	9.6E+01
1958	4.0E+10	3.6E-02	4.0E-02	3.6E-02	3.6E-02		4.0E-02	4.0E-02	9.5E+01
1959	3.4E+10	8.0E-03	1.0E-02	1.7E-02	9.2E-03		1.7E-02	1.7E-02	4.0E+01
1960	7.4E+10	6.1E-03	6.2E-03	1.1E-02	7.0E-03		1.1E-02	1.1E-02	2.6E+01
1961	8.9E+10	2.7E-03	2.4E-03	4.8E-03	2.5E-03		4.8E-03	4.8E-03	1.2E+01
1962	4.8E+10	1.9E-03	1.7E-03	3.0E-03	2.4E-03		3.0E-03	3.0E-03	7.1E+00
1963	4.8E+10	1.9E-03	1.7E-03	3.0E-03	2.4E-03		3.0E-03	3.0E-03	7.1E+00
1964	2.2E+10	2.6E-03	2.2E-03	3.7E-03	3.7E-03		3.7E-03	3.7E-03	8.9E+00
1965	7.4E+08	7.4E-04	7.4E-04	1.1E-03	7.4E-04		1.1E-03	1.1E-03	2.7E+00
1966	7.4E+08	7.4E-04	7.4E-04	7.4E-04	7.4E-04		7.4E-04	7.4E-04	1.8E+00
1967	7.4E+08	7.4E-04	7.4E-04	7.4E-04	7.4E-04		7.4E-04	7.4E-04	1.8E+00
1968	1.1E+10	7.4E-04	7.4E-04	1.5E-03	7.4E-04		1.5E-03	1.5E-03	3.6E+00
1969	3.7E+10	7.4E-04	7.4E-04	1.5E-03	1.1E-03		1.5E-03	1.5E-03	3.6E+00
1970	1.9E+10	7.4E-04	7.4E-04	7.4E-04	1.5E-03		1.5E-03	1.5E-03	3.6E+00
1971	2.6E+10	7.4E-04	7.4E-04	1.1E-03	1.5E-03		1.5E-03	1.5E-03	3.6E+00
1972	2.6E+10	7.4E-04	7.4E-04	1.1E-03	1.1E-03		1.1E-03	1.1E-03	2.7E+00
1973	3.0E+10	7.4E-04	8.1E-04	3.9E-03	1.1E-03		3.9E-03	3.9E-03	9.4E+00
1974	2.2E+10	3.3E-04	4.1E-04	1.5E-03	4.1E-04		1.5E-03	1.5E-03	3.5E+00
1975	2.6E+10	6.7E-04	1.0E-03	3.2E-03	8.5E-04		3.2E-03	3.2E-03	7.6E+00
1976	3.3E+10	1.0E-03	1.0E-03	3.2E-03	5.2E-04		3.2E-03	3.2E-03	7.6E+00
1977	1.5E+10	4.1E-04	5.2E-04	2.2E-03	7.4E-04		2.2E-03	2.2E-03	5.3E+00
1978	1.5E+09	3.3E-04	5.2E-04	1.0E-03	1.5E-04		1.0E-03	1.0E-03	2.4E+00
1979	7.4E+08	1.5E-04	1.9E-04	1.0E-03	5.2E-04		1.0E-03	1.0E-03	2.4E+00
1980	3.7E+07	2.2E-04	2.2E-04	7.8E-04	3.3E-04		7.8E-04	7.8E-04	1.9E+00
1981	1.9E+09	1.1E-04	1.9E-04	3.0E-04	3.0E-04		3.0E-04	3.0E-04	7.1E-01
1982	4.8E+09	1.1E-04	1.5E-04	4.1E-04	1.9E-04		4.1E-04	4.1E-04	9.8E-01
1983	1.7E+08	2.2E-04	3.0E-04	2.2E-04	2.6E-04		3.0E-04	3.0E-04	7.1E-01
1984	7.0E+07	3.0E-04	1.9E-04	4.8E-04	3.3E-04		4.8E-04	4.8E-04	1.2E+00
1985	1.4E+08	4.4E-04	2.2E-04	4.1E-04	4.8E-04		4.8E-04	4.8E-04	1.2E+00
1986	1.3E+07	2.6E-04	3.0E-04	3.0E-04	2.6E-04		3.0E-04	3.0E-04	7.1E-01
1987	1.1E+07	1.3E-04	1.3E-04	1.4E-04	1.3E-04		1.4E-04	1.4E-04	3.4E-01
1988	2.2E+06	1.6E-04	1.5E-04	1.5E-04	2.0E-04		2.0E-04	2.0E-04	4.7E-01
1989	1.1E+07	9.3E-05	1.1E-04	1.3E-04	8.9E-05		1.3E-04	1.3E-04	3.2E-01
1990	1.2E+06					1.2E-04		1.2E-04	3.0E-01
1991	2.5E+05	5.2E-05	9.3E-05	7.8E-05	4.8E-05		9.3E-05	9.3E-05	2.2E-01
1992	7.8E+07	5.6E-05	5.9E-05	4.8E-05	5.2E-05		5.9E-05	5.9E-05	1.4E-01
1993	1.2E+08					8.0E-05		8.0E-05	1.9E-01
1994		7.0E-05	1.3E-04	2.0E-04	9.3E-05		2.0E-04	2.0E-04	4.8E-01
1995									
1996	1.1E+08								
1997									
1998									
1999									
2000									
2001									

During the early period of PGDP operations, significant quantities of depleted uranium cylinders would not have been stored at the site. As production continued, the inventory of depleted uranium and associated direct radiation levels increased.

Table 4-3. Technetium-99 releases, beta airborne concentrations, and ^{99}Tc intake.

Year	Tc-99 release (Bq/yr)	Outdoor beta concentrations (Bq/m^3) at certain monitoring stations							Tc-99 intake (Bq/yr)
		2 PS beta	5 PW beta	6 PN beta	8 PE beta	Estimate	Maximum	Applied	
1952									
1953									
1954						2.4E-02		2.4E-02	5.7E+01
1955	3.7E+10					2.4E-02		2.4E-02	5.7E+01
1956	3.7E+10					3.8E-02		3.8E-02	9.1E+01
1957	9.6E+10					2.0E-01		2.0E-01	4.8E+02
1958	9.6E+10					2.0E-01		2.0E-01	4.8E+02
1959	1.8E+11					3.7E-01		3.7E-01	8.9E+02
1960	2.3E+11					4.9E-01		4.9E-01	1.2E+03
1961	1.9E+11	5.1E-02	7.6E-02	1.0E-01	7.1E-02		1.0E-01	1.0E-01	2.4E+02
1962	1.5E+11	4.0E-02	3.2E-02	9.8E-02	8.1E-02		9.8E-02	9.8E-02	2.4E+02
1963	1.6E+11	9.6E-02	9.6E-02	1.6E-01	1.0E-01		1.6E-01	1.6E-01	3.9E+02
1964	1.5E+11	1.8E-01	2.0E-01	3.2E-01	2.6E-01		3.2E-01	3.2E-01	7.6E+02
1965	1.6E+11	1.8E-01	2.0E-01	3.2E-01	2.6E-01		3.2E-01	3.2E-01	7.6E+02
1966	2.0E+11	3.3E-02	3.3E-02	8.5E-02	6.7E-02		8.5E-02	8.5E-02	2.0E+02
1967	1.6E+11	7.4E-03	1.1E-02	1.5E-02	1.1E-02		1.5E-02	1.5E-02	3.6E+01
1968	3.7E+09	5.6E-03	5.9E-03	1.2E-02	7.0E-03		1.2E-02	1.2E-02	2.9E+01
1969	3.7E+09	4.4E-03	5.2E-03	4.8E-03	8.5E-03		8.5E-03	8.5E-03	2.0E+01
1970	3.7E+09	5.6E-03	7.4E-03	3.5E-02	6.7E-03		3.5E-02	3.5E-02	8.4E+01
1971	3.7E+09	1.0E-02	1.9E-02	5.9E-02	3.5E-02		5.9E-02	5.9E-02	1.4E+02
1972	1.2E+11	6.7E-03	1.1E-02	2.4E-02	1.4E-02		2.4E-02	2.4E-02	5.7E+01
1973	1.1E+11	1.5E-02	1.9E-02	1.0E-01	2.6E-02		1.0E-01	1.0E-01	2.5E+02
1974	3.7E+09	1.1E-02	1.9E-02	8.9E-02	3.0E-02		8.9E-02	8.9E-02	2.1E+02
1975	1.3E+11	8.5E-03	1.6E-02	1.5E-01	6.1E-02		1.5E-01	1.5E-01	3.6E+02
1976	2.2E+11	7.6E-03	8.3E-03	1.3E-02	8.1E-03		1.3E-02	1.3E-02	3.2E+01
1977	3.0E+10	6.7E-03	7.8E-03	1.8E-02	7.8E-03		1.8E-02	1.8E-02	4.3E+01
1978	3.7E+09	5.2E-03	5.9E-03	1.4E-02	7.0E-03		1.4E-02	1.4E-02	3.5E+01
1979	3.7E+09	5.2E-03	5.2E-03	1.7E-02	9.6E-03		1.7E-02	1.7E-02	4.1E+01
1980	2.2E+09	7.8E-03	7.4E-03	1.0E-02	9.6E-03		1.0E-02	1.0E-02	2.4E+01
1981	2.2E+09	5.6E-03	5.6E-03	7.0E-03	5.6E-03		1.3E-02	1.3E-02	3.1E+01
1982	2.0E+09	5.9E-03	5.9E-03	9.6E-03	7.4E-03		9.6E-03	9.6E-03	2.3E+01
1983	2.2E+08	1.1E-02	1.3E-02	1.4E-02	1.3E-02		1.4E-02	1.4E-02	3.3E+01
1984	3.7E+08	7.8E-03	7.8E-03	1.1E-02	7.4E-03		1.1E-02	1.1E-02	2.8E+01
1985	1.1E+08	7.8E-03	1.0E-02	1.2E-02	1.3E-02		1.3E-02	1.3E-02	3.0E+01
1986	1.3E+09	1.2E-02	9.6E-03	1.6E-02	1.2E-02		1.6E-02	1.6E-02	3.7E+01
1987	5.7E+08	8.5E-03	7.4E-03	1.1E-02	8.1E-03		1.3E-02	1.3E-02	3.2E+01
1988	3.3E+08	6.7E-03	4.8E-03	6.3E-03	5.2E-03		7.3E-03	7.3E-03	1.7E+01
1989	3.3E+07	3.3E-03	2.9E-03	3.7E-03	3.4E-03		4.4E-03	4.4E-03	1.1E+01
1990	1.4E+08	1.2E-03	1.7E-03	1.4E-03	1.4E-03		1.7E-03	1.7E-03	4.0E+00
1991	1.3E+08	1.2E-03	1.3E-03	1.3E-03	1.1E-03		1.3E-03	1.3E-03	3.2E+00
1992	1.4E+07	1.1E-03	1.1E-03	1.2E-03	1.2E-03		1.2E-03	1.2E-03	2.9E+00
1993	1.1E+08	9.3E-04	9.3E-04	1.0E-03	8.5E-04		1.1E-03	1.1E-03	2.8E+00
1994	7.6E+06	7.4E-04	5.6E-04	7.4E-04	7.0E-04		8.5E-04	8.5E-04	2.0E+00
1995	1.2E+09					3.0E-03		3.0E-03	7.2E+00
1996		1.0E-03	1.2E-03	1.3E-03	1.0E-03		1.3E-03	1.3E-03	3.1E+00
1997						3.0E-03		3.0E-03	7.2E+00
1998	1.5E+09					3.0E-03		3.0E-03	7.2E+00
1999	1.1E+08					3.0E-03		3.0E-03	7.2E+00
2000						3.0E-03		3.0E-03	7.2E+00
2001						3.0E-03		3.0E-03	7.2E+00

Unmonitored workers in the early years did not have significant inventories of depleted uranium to contribute to external dose. Later, unmonitored workers would not spend their entire work year at the depleted cylinder storage yards and, therefore, would not reach the maximum dose recorded by fence line monitoring. No other significant sources of external exposure are associated with the PGDP operations. An assumed deep dose equivalent rate of 200 mrem/yr for all years would be reasonable, and deficiencies in earlier measurement techniques thereby become immaterial.

4.3.1 Ambient Radiation

The environmental radiological profile has been developed for PGDP for use by dose reconstructors when personal dosimetry or bioassay program participation was not required. Site annual environmental reports, health physics surveys, and other reports were reviewed for data that would be useful in reconstructing ambient radiation levels. Ambient radiation includes natural background and that from the facility.

Data in these documents (see the reference list for citations) include TLD radiation measurements. Table 4-4 lists TLD results. Figure 4-4 shows the locations of TLDs at PGDP.

Table 4-4. External dose equivalent rates, PGDP external gamma exposure rate of mrem/2,000 hr.

TLD location	1	2	3	4	5	6	7	8	9	10	11	12	13	25	30	47	48	50	51	52	53	Reported background
1961	42			42															42	63		
1986	31	25	25	23	14																	
1989	112			10				9			5	8	6		10				28	114		
1990	98			14				16			17	18	15		13				35	15		
1991	92			12				14			10	14	11		13				40	19		
1992	84			12				14			10	9	11		13				40	58		
1993	110			21				20			21	20	18		21				39	20		10
1998	120	106	234																			28
1999	101	174	180											26								24
2000	101	179	112	23	24	22	27	18	25	21	23	22	26	29	20							25
2001	120	194	103	26	27	24	29	20	26	23	25	24	28		23	56	35	41	39	31	71	27

The ambient radiation measured by TLDs near the security fence included natural background radiation, nuclear weapons testing fallout, and cosmic radiation. The TLDs provided an indication of worker exposure levels in the general proximity of the security fence, but not inside buildings. Table 4-4 lists annual exposure levels for locations near the security fence. These data have been adjusted to be representative of exposure for a 2,000-hr work year.

Observations reported in the early environmental reports, based on surveys with portable instruments, state "0.02 mrem/hr at all locations." The instrumentation was less advanced by today's standards and did not provide continuous monitoring, so the results produced are overshadowed by recent, more reliable observations.

PGDP personnel have annually compared these data with TLD data from offsite locations and literature values for State and regional exposure levels. The determination has always been that onsite ambient radiological conditions as measured at the security fence are not significantly different from offsite, State, and regional annual exposure levels. This is attributed to the geology of the region around PGDP. Exceptions to this observation have been monitoring locations near depleted uranium cylinder storage yards in recent years. These locations show an increase in external exposure as the inventory of depleted uranium increased. Recommendations for external exposure in this TBD include background environmental radiation.

4.3.2 Radiological Conditions in Cylinder Storage Yards

Several fence line TLDs were adjacent to the uranium hexafluoride (UF_6) cylinder storage yards and, due to their proximity (less than 100 m), represent within a certain amount of confidence the dose rate ranges near the storage yards. Workers performed activities in other facilities and probably did not work in the cylinder yards 2,000 hr a year without dosimetry. During recent years this area has been posted as a radiological area, which has reduced the number of unmonitored workers spending any significant time in the area to zero.

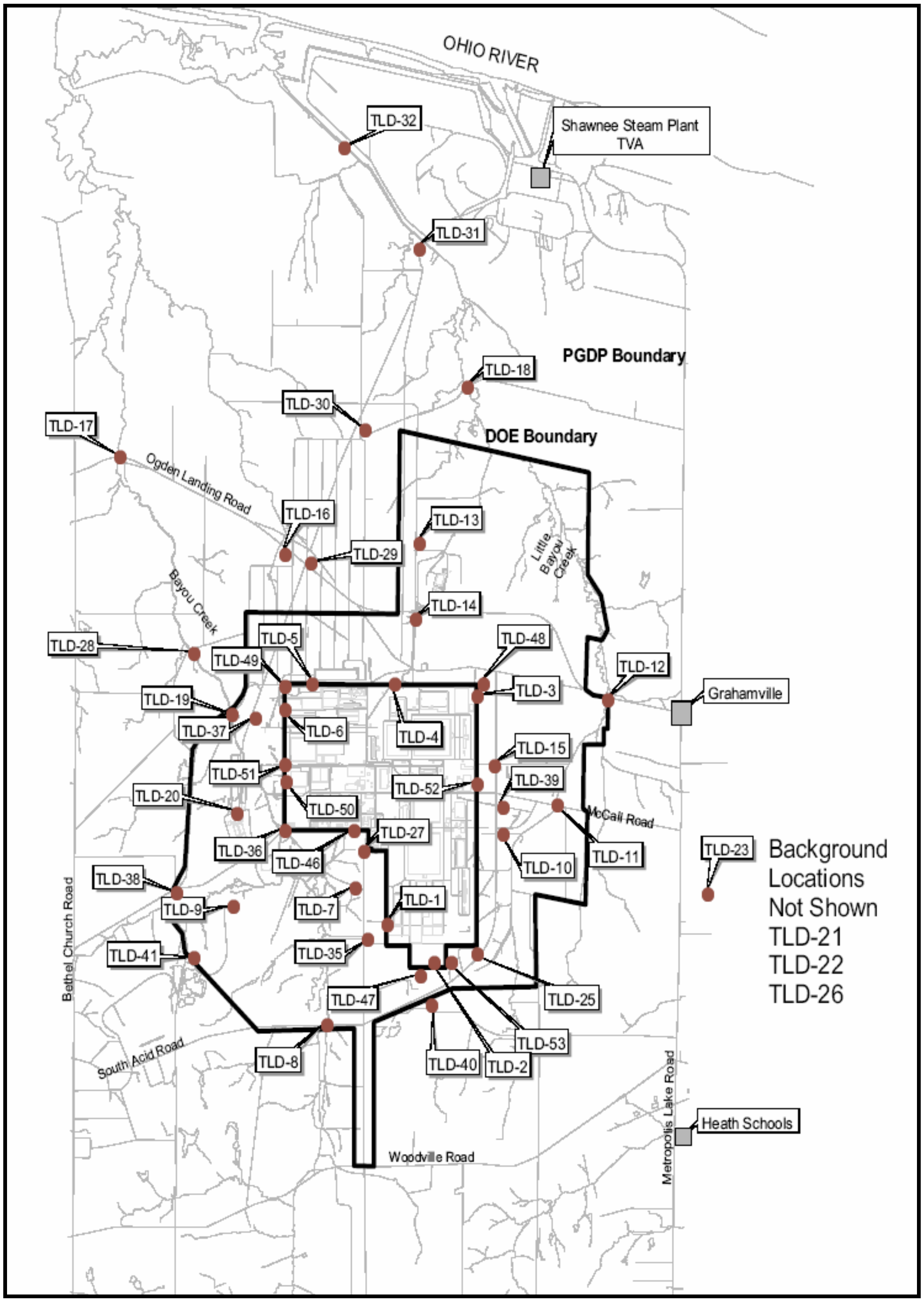

Figure 4-4. 2001 TLD locations.

Given this information, an ambient annual radiation dose equivalent of 200 mrem should be applied to unmonitored workers.

4.3.3 Radiological Conditions Inside Buildings

Because all workers were badged and monitored throughout much of the PGDP operating history, coworker exposure data can be used to assign dose to unmonitored workers for those periods in which all workers were not badged or were badged but not analyzed. Other sources of information that describe potential radiation exposures can be used as backup to the coworker data.

4.4 UNCERTAINTY

The locations of the monitoring points add uncertainty to the results. The monitoring points, as stated above, have been located around the PGDP perimeter and off the site to monitor public exposures. Before 1998, external environmental exposures were not monitored in relation to workers; that is, monitoring stations were not normally placed at the interior of the site among the process buildings. Because of data availability, therefore, this analysis used public exposure information for worker environmental exposures. The maximum value of environmental exposure is recommended for years when data are unavailable to compensate for lack of worker-specific environmental dose information.

All external environmental dose data were adjusted to reflect a 2,000-hr work year. The data were originally reported in site environmental reports as representative of an employee who worked at the site 24 hours a day, 365 days a year. Using an employee permanently on the site, however, is an unrealistic assumption that would clearly overstate onsite environmental exposures.

Uncertainty related to internal exposures presents similar concerns. The highest internal exposures occurred during the early years, and lessened over time with increased controls and better equipment. Assumption of the maximum uptake for all years reduces the need to include an uncertainty factor (other than default values) for intakes.

In summary, external exposure rose over time as the depleted uranium inventory grew, and internal exposure decreased as releases were reduced, providing offsetting factors to ensure claimant favorability. Therefore, the external dose equivalent that can be applied though the history of PGDP is 200 mrem/yr. Reconstructions should estimate annual intakes using the information in Section 4.2.5.

REFERENCES

Cited References

CCC (Carbide and Carbon Chemicals Company), 1953, *Water, Mud & Air Survey at the Paducah Plant*, KYL-11 (LB09905-0221), Paducah, Kentucky.

DOE (U.S. Department of Energy), 1989, *Paducah Gaseous Diffusion Plant Site Environmental Report for 1988*, ES/ESH-8/V3, Martin Marietta Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1994, *Paducah Gaseous Diffusion Plant Annual Site Environmental Report for 1993*, Martin Marietta Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1996, *U.S. Department of Energy Paducah Site Annual Environmental Report for 1994*, Lockheed Martin Energy Systems, Oak Ridge, Tennessee.

Union Carbide (Union Carbide Nuclear Company), 1959, *Environmental Monitoring Summary, Paducah Plant for 1958*, KY-273, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1960, *Environmental Monitoring Summary, Paducah Plant for 1959*, KY-332, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1961, *Environmental Monitoring Summary, Paducah Plant for 1960*, KY-371, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1962a, “Film Badge Procedure,” Health Physics and Industrial Hygiene Department, PGDP EM&EF Records Transmittal List, 9/1/62 (H-00013-0575), Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1962b, “Air Monitoring Procedure,” PGDP EM&EF Records Transmittal List, 9/1/62 (H-00013-0575), File Copy.

Other References

DOE (U.S. Department of Energy) 1988, *Environmental Surveillance of the U.S. Department of Energy Paducah Gaseous Diffusion Plant and Surrounding Environs During 1987*, ES/ESH-4/V3, Martin Marietta Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1980, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1979*, Y/UB-14, Union Carbide Nuclear Company, Paducah, Kentucky.

DOE (U.S. Department of Energy), 1981, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1980*, KY-717, Union Carbide Nuclear Company, Paducah, Kentucky.

DOE (U.S. Department of Energy), 1982, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1981*, KY-724, Union Carbide Nuclear Company, Paducah, Kentucky.

DOE (U.S. Department of Energy), 1983, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1982*, KY-731, Union Carbide Nuclear Company, Paducah, Kentucky.

DOE (U.S. Department of Energy), 1984, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant, Calendar Year 1983*, KY-742, Martin Marietta Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1985, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1984*, KY-747, Martin Marietta Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1986, *Paducah Uranium Enrichment Complex Environmental Monitoring Report for Calendar Year 1985*, KY-755, Martin Marietta Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1987, *Environmental Surveillance of the U.S. Department of Energy Paducah Gaseous Diffusion Plant and Surrounding Environs During 1986*, Martin Marietta Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1990, *Paducah Gaseous Diffusion Plant Environmental Report for 1989*, ES/ESH-13/V3, Martin Marietta Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1991, *Paducah Gaseous Diffusion Plant Environmental Report for 1990*, ES/ESH-18/V3, Martin Marietta Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1992, *Paducah Gaseous Diffusion Plant Environmental Report for 1991*, ES/ESH-22/V3, Martin Marietta Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1993, *Paducah Gaseous Diffusion Plant Environmental Report for 1992*, Martin Marietta Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1997a, *U.S. Department of Energy Paducah Annual Environmental Report for 1995*, Lockheed Martin Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1997b, *U.S. Department of Energy Paducah Annual Environmental Data for 1996*, Lockheed Martin Energy Systems, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1998, *U.S. Department of Energy Paducah Annual Environmental Data for 1997*, Bechtel Jacobs Company, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 1999, *U.S. Department of Energy Paducah Annual Environmental Data for 1998*, Bechtel Jacobs Company, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 2001a, *U.S. Department of Energy Paducah Annual Environmental Data for 1999*, Bechtel Jacobs Company, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 2001b, *Paducah Site Annual Site Environmental Report for Calendar Year 2000*, BJC/PAD-237, Bechtel Jacobs Company, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 2002a, *Environmental Monitoring Results, Annual Site Environmental Report for Calendar Year 2001, Paducah Gaseous Diffusion Plant*, BJC/PAD-319, Vol. II, Bechtel Jacobs Company, Oak Ridge, Tennessee.

DOE (U.S. Department of Energy), 2002b, *Paducah Site Annual Site Environmental Report, 2001*, BJC/PAD-319, Volume I, Bechtel Jacobs Company, Oak Ridge, Tennessee.

Union Carbide (Union Carbide Nuclear Company), 1962c, *Environmental Monitoring Summary, Paducah Plant for 1961*, KY-419, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1964, *Environmental Monitoring Summary, Paducah Plant for 1962 and 1963*, KY-458, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1965, *Environmental Monitoring Summary, Paducah Plant for 1964*, KY-484, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1967, *Environmental Monitoring Summary, Paducah Plant for 1965 and 1966*, KY-624, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1969, *Environmental Monitoring Summary, Paducah Plant for 1967 and 1968*, KY-582, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1970, *Environmental Monitoring Summary, Paducah Plant for 1969*, KY-624, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1971, *Environmental Monitoring Summary, Paducah Plant for 1970*, KY-629, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1972, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1971*, UCC-ND-222, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1973, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1972*, UCC-ND-245, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1974, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1973*, UCC-ND-279, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1975, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1974*, UCC-ND-303, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1976, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1975*, Y/UB-5, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1977, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1976*, Y/UB-7, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1978a, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1977*, Y/UB-9, Paducah, Kentucky.

Union Carbide (Union Carbide Nuclear Company), 1978b, *Environmental Monitoring Report, Paducah Gaseous Diffusion Plant for Calendar Year 1978*, Y/UB-11, Paducah, Kentucky.

GLOSSARY

alpha radiation
Radiation consisting of charged particles identical with the isotope ^4He.

background radiation
Radiation received that is not associated with a worker's occupation. This includes cosmic and terrestrial sources.

becquerel (Bq)
The derived International System unit of radioactivity equal to one disintegration per second.

beta radiation
Radiation consisting of electrons emitted spontaneously from the nuclei of certain radioactive elements.

deep dose equivalent
Dose equivalent at a depth of 1.0 cm in soft tissue.

dosimetry
The science of assessing absorbed dose, dose equivalent, effective dose equivalent, etc., from external and/or internal sources of radiation.

exposure
As used in the technical sense, ionization produced by photons per unit mass (2.58×10^{-4} coulomb/kilogram).

radioactivity
The spontaneous emission of radiation, generally alpha or beta particles, gamma rays, and neutrons from unstable nuclei.

rem
A unit of dose equivalent.

thermoluminescent dosimeter
A holder containing solid chips of material that when heated release the stored energy as light. The measurement of this light provides a measurement of absorbed dose.

uranium hexafluoride (UF_6) cylinder storage yard
Site for maintenance of cylinders containing depleted UF_6. The cylinders typically weigh 10 and 14 tons. The depleted UF_6 is primarily in a solid form. There are storage yards at PGDP and the Oak Ridge K-25 site.

ATTACHMENT 4A

OUTDOOR BETA AND ALPHA CONCENTRATIONS

Table 4A-1. Outdoor beta concentrations.

Year	Release (Bq/yr) Tc-99	Outdoor beta concentrations (Bq/m^3) at each monitoring location															Bq/yr Uptake
		2 PS beta	5 PW beta	6 PN beta	8 PE beta	BN	BE	IN	IE	ISE	IS	IW	GR	Estimate	Maximum	Applied	
1952																	
1953																	
1954														2.4E-02		2.4E-02	5.7E+01
1955	3.7E+10													2.4E-02		2.4E-02	5.7E+01
1956	3.7E+10													3.8E-02		3.8E-02	9.1E+01
1957	9.6E+10													2.0E-01		2.0E-01	4.8E+02
1958	9.6E+10													2.0E-01		2.0E-01	4.8E+02
1959	1.8E+11													3.7E-01		3.7E-01	8.9E+02
1960	2.3E+11													4.9E-01		4.9E-01	1.2E+03
1961	1.9E+11	5.1E-02	7.6E-02	1.0E-01	7.1E-02										1.0E-01	1.0E-01	2.4E+02
1962	1.5E+11	4.0E-02	3.2E-02	9.8E-02	8.1E-02										9.8E-02	9.8E-02	2.4E+02
1963	1.6E+11	9.6E-02	9.6E-02	1.6E-01	1.0E-01			8.1E-02	8.5E-02		1.2E-01	8.9E-02			1.6E-01	1.6E-01	3.9E+02
1964	1.5E+11	1.8E-01	2.0E-01	3.2E-01	2.6E-01			2.0E-01	1.8E-01		1.9E-01	1.8E-01			3.2E-01	3.2E-01	7.6E+02
1965	1.6E+11	1.8E-01	2.0E-01	3.2E-01	2.6E-01			2.0E-01	1.8E-01		1.9E-01	1.8E-01			3.2E-01	3.2E-01	7.6E+02
1966	2.0E+11	3.3E-02	3.3E-02	8.5E-02	6.7E-02			3.3E-02	3.3E-02		3.3E-02	3.3E-02			8.5E-02	8.5E-02	2.0E+02
1967	1.6E+11	7.4E-03	1.1E-02	1.5E-02	1.1E-02			1.1E-02	1.1E-02		1.1E-02	1.1E-02			1.5E-02	1.5E-02	3.6E+01
1968	3.7E+09	5.6E-03	5.9E-03	1.2E-02	7.0E-03			6.3E-03	6.7E-03		7.0E-03	6.3E-03			1.2E-02	1.2E-02	2.9E+01
1969	3.7E+09	4.4E-03	5.2E-03	4.8E-03	8.5E-03			5.6E-03	5.2E-03	6.7E-03	6.7E-03	3.3E-03			8.5E-03	8.5E-03	2.0E+01
1970	3.7E+09	5.6E-03	7.4E-03	3.5E-02	6.7E-03			7.8E-03	6.7E-03	6.7E-03	6.7E-03	7.4E-03			3.5E-02	3.5E-02	8.4E+01
1971	3.7E+09	1.0E-02	1.9E-02	5.9E-02	3.5E-02			8.9E-03	6.7E-03	8.5E-03	8.5E-03	7.4E-03			5.9E-02	5.9E-02	1.4E+02
1972	1.2E+11	6.7E-03	1.1E-02	2.4E-02	1.4E-02			8.5E-03	1.7E-02	7.4E-03	7.4E-03	7.4E-03			2.4E-02	2.4E-02	5.7E+01
1973	1.1E+11	1.5E-02	1.9E-02	1.0E-01	2.6E-02			1.5E-02	1.1E-02	1.1E-02	1.1E-02	7.4E-03			1.0E-01	1.0E-01	2.5E+02
1974	3.7E+09	1.1E-02	1.9E-02	8.9E-02	3.0E-02			1.1E-02	7.4E-03	7.4E-03	7.4E-03	7.4E-03			8.9E-02	8.9E-02	2.1E+02
1975	1.3E+11	8.5E-03	1.6E-02	1.5E-01	6.1E-02	1.6E-02		9.3E-03	5.6E-03	4.8E-03	3.7E-03	4.8E-03			1.5E-01	1.5E-01	3.6E+02
1976	2.2E+11	7.6E-03	8.3E-03	1.3E-02	8.1E-03	8.9E-03		7.6E-03	7.2E-03	7.9E-03	7.4E-03	7.4E-03			1.3E-02	1.3E-02	3.2E+01
1977	3.0E+10	6.7E-03	7.8E-03	1.8E-02	7.8E-03	8.1E-03		7.8E-03	7.4E-03	8.1E-03	6.7E-03	6.7E-03			1.8E-02	1.8E-02	4.3E+01
1978	3.7E+09	5.2E-03	5.9E-03	1.4E-02	7.0E-03	7.0E-03		5.6E-03	6.3E-03	5.9E-03	5.6E-03	5.6E-03			1.4E-02	1.4E-02	3.5E+01
1979	3.7E+09	5.2E-03	5.2E-03	1.7E-02	9.6E-03	7.4E-03		4.8E-03	5.9E-03	4.8E-03	5.2E-03	5.2E-03			1.7E-02	1.7E-02	4.1E+01
1980	2.2E+09	7.8E-03	7.4E-03	1.0E-02	9.6E-03	8.9E-03		8.1E-03	9.6E-03	7.8E-03	7.8E-03	7.0E-03			1.0E-02	1.0E-02	2.4E+01
1981	2.2E+09	5.6E-03	5.6E-03	7.0E-03	5.6E-03	5.9E-03	5.6E-03	5.2E-03	5.2E-03	5.9E-03	5.6E-03	5.6E-03	1.3E-02		1.3E-02	1.3E-02	3.1E+01
1982	2.0E+09	5.9E-03	5.9E-03	9.6E-03	7.4E-03	6.3E-03	7.0E-03	5.6E-03	5.6E-03	5.2E-03	6.3E-03	4.8E-03	5.2E-03		9.6E-03	9.6E-03	2.3E+01
1983	2.2E+08	1.1E-02	1.3E-02	1.4E-02	1.3E-02	1.2E-02	1.3E-02	1.1E-02	9.6E-03	1.0E-02	1.2E-02	8.1E-03	1.3E-02		1.4E-02	1.4E-02	3.3E+01
1984	3.7E+08	7.8E-03	7.8E-03	1.1E-02	7.4E-03	7.8E-03	6.7E-03	7.8E-03	8.5E-03	6.3E-03	7.4E-03	6.7E-03	8.5E-03		1.1E-02	1.1E-02	2.8E+01
1985	1.1E+08	7.8E-03	1.0E-02	1.2E-02	1.3E-02	1.0E-02	1.1E-02	7.8E-03	6.7E-03	1.0E-02	1.0E-02	8.5E-03	8.5E-03		1.3E-02	1.3E-02	3.0E+01
1986	1.3E+09	1.2E-02	9.6E-03	1.6E-02	1.2E-02	1.2E-02	1.1E-02	1.1E-02	1.3E-02	7.4E-03	8.5E-03	1.1E-02	1.3E-02		1.6E-02	1.6E-02	3.7E+01
1987	5.7E+08	8.5E-03	7.4E-03	1.1E-02	8.1E-03	1.0E-02	9.3E-03	9.6E-03	5.9E-03	1.3E-02	8.9E-03	1.3E-02	1.0E-02		1.3E-02	1.3E-02	3.2E+01
1988	3.3E+08	6.7E-03	4.8E-03	6.3E-03	5.2E-03	5.3E-03	7.1E-03	7.3E-03	5.7E-03	6.1E-03	4.6E-03	6.4E-03	6.4E-03		7.3E-03	7.3E-03	1.7E+01
1989	3.3E+07	3.3E-03	2.9E-03	3.7E-03	3.4E-03	3.4E-03	3.6E-03	4.1E-03	4.1E-03	4.4E-03	3.3E-03	3.5E-03	3.7E-03		4.4E-03	4.4E-03	1.1E+01
1990	1.4E+08	1.2E-03	1.7E-03	1.4E-03	1.4E-03	1.1E-03	1.3E-03	1.5E-03	1.3E-03	1.3E-03	1.5E-03	1.5E-03	1.4E-03		1.7E-03	1.7E-03	4.0E+00
1991	1.3E+08	1.2E-03	1.3E-03	1.3E-03	1.1E-03	1.3E-03	1.3E-03	1.2E-03	1.1E-03	1.1E-03	1.2E-03	1.1E-03	1.1E-03		1.3E-03	1.3E-03	3.2E+00
1992	1.4E+07	1.1E-03	1.1E-03	1.2E-03	1.2E-03	1.1E-03	1.1E-03	1.1E-03	1.2E-03	1.1E-03	1.1E-03	1.1E-03	1.2E-03		1.2E-03	1.2E-03	2.9E+00
1993	1.1E+08	9.3E-04	9.3E-04	1.0E-03	8.5E-04	8.1E-04	8.5E-04	1.1E-03	7.8E-04	9.3E-04	9.3E-04	1.0E-03	7.8E-04		1.1E-03	1.1E-03	2.8E+00
1994	7.6E+06	7.4E-04	5.6E-04	7.4E-04	7.0E-04	8.5E-04	6.7E-04	8.1E-04	8.5E-04	8.1E-04	8.5E-04	8.1E-04	7.8E-04		8.5E-04	8.5E-04	2.0E+00
1995	1.2E+09													3.0E-03		3.0E-03	7.2E+00
1996		1.0E-03	1.2E-03	1.3E-03	1.0E-03		1.1E-03	1.2E-03	1.2E-03	1.1E-03	1.2E-03	1.1E-03	1.3E-03		1.3E-03	1.3E-03	3.1E+00
1997														3.0E-03		3.0E-03	7.2E+00
1998	1.5E+09													3.0E-03		3.0E-03	7.2E+00
1999	1.1E+08													3.0E-03		3.0E-03	7.2E+00
2000														3.0E-03		3.0E-03	7.2E+00
2001														3.0E-03		3.0E-03	7.2E+00

Table 4A-2. Outdoor alpha concentrations.

Year	Release (Bq/yr) U	Outdoor alpha concentrations (Bq/m^3) at each monitoring location															(Bq/yr)
		2 PS alpha	5 PW alpha	6 PN alpha	8 PE alpha	BN	BE	IN	IE	ISE	IS	IW	GR	Estimate for missing years	Maximum reported	Applied concentration	Annual uranium intake
1952	7.4E+08													7.3E-04		7.3E-04	1.7E+00
1953	9.3E+09													9.1E-03		9.1E-03	2.2E+01
1954	8.9E+10													8.7E-02		8.7E-02	2.1E+02
1955	1.6E+11													1.5E-01		1.5E-01	3.7E+02
1956	6.0E+10													5.9E-02		5.9E-02	1.4E+02
1957	4.1E+10													4.0E-02		4.0E-02	9.6E+01
1958	4.0E+10	3.6E-02	4.0E-02	3.6E-02	3.6E-02										4.0E-02	4.0E-02	9.5E+01
1959	3.4E+10	8.0E-03	1.0E-02	1.7E-02	9.2E-03										1.7E-02	1.7E-02	4.0E+01
1960	7.4E+10	6.1E-03	6.2E-03	1.1E-02	7.0E-03										1.1E-02	1.1E-02	2.6E+01
1961	8.9E+10	2.7E-03	2.4E-03	4.8E-03	2.5E-03										4.8E-03	4.8E-03	1.2E+01
1962	4.8E+10	1.9E-03	1.7E-03	3.0E-03	2.4E-03										3.0E-03	3.0E-03	7.1E+00
1963	4.8E+10	1.9E-03	1.7E-03	3.0E-03	2.4E-03			2.7E-03	2.6E-03		2.7E-03	2.7E-03			3.0E-03	3.0E-03	7.1E+00
1964	2.2E+10	2.6E-03	2.2E-03	3.7E-03	3.7E-03			1.7E-03	1.7E-03	1.7E-03	1.4E-03	1.4E-03			3.7E-03	3.7E-03	8.9E+00
1965	7.4E+08	7.4E-04	7.4E-04	1.1E-03	7.4E-04			1.7E-03	1.7E-03	1.7E-03	1.4E-03	1.4E-03			1.1E-03	1.1E-03	2.7E+00
1966	7.4E+08	7.4E-04	7.4E-04	7.4E-04	7.4E-04			2.0E-03	2.5E-03	2.8E-03	1.9E-03	2.8E-03			7.4E-04	7.4E-04	1.8E+00
1967	7.4E+08	7.4E-04	7.4E-04	7.4E-04	7.4E-04			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			7.4E-04	7.4E-04	1.8E+00
1968	1.1E+10	7.4E-04	7.4E-04	1.5E-03	7.4E-04			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.5E-03	1.5E-03	3.6E+00
1969	3.7E+10	7.4E-04	7.4E-04	1.5E-03	1.1E-03			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.5E-03	1.5E-03	3.6E+00
1970	1.9E+10	7.4E-04	7.4E-04	7.4E-04	1.5E-03			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.5E-03	1.5E-03	3.6E+00
1971	2.6E+10	7.4E-04	7.4E-04	1.1E-03	1.5E-03			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.5E-03	1.5E-03	3.6E+00
1972	2.6E+10	7.4E-04	7.4E-04	1.1E-03	1.1E-03			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.1E-03	1.1E-03	2.7E+00
1973	3.0E+10	7.4E-04	8.1E-04	3.9E-03	1.1E-03			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			3.9E-03	3.9E-03	9.4E+00
1974	2.2E+10	3.3E-04	4.1E-04	1.5E-03	4.1E-04			7.4E-04	7.4E-04	7.4E-04	7.4E-04	7.4E-04			1.5E-03	1.5E-03	3.5E+00
1975	2.6E+10	6.7E-04	1.0E-03	3.2E-03	8.5E-04	1.8E-03		7.4E-04	7.4E-04	7.4E-04	3.3E-04	3.3E-04			3.2E-03	3.2E-03	7.6E+00
1976	3.3E+10	1.0E-03	1.0E-03	3.2E-03	5.2E-04	4.1E-04		3.3E-04	3.3E-04	3.3E-04	3.3E-04	3.3E-04			3.2E-03	3.2E-03	7.6E+00
1977	1.5E+10	4.1E-04	5.2E-04	2.2E-03	7.4E-04	1.0E-03		6.7E-04	1.0E-03	1.0E-03	6.7E-04	6.7E-04			2.2E-03	2.2E-03	5.3E+00
1978	1.5E+09	3.3E-04	5.2E-04	1.0E-03	1.5E-04	8.1E-04		1.2E-03	1.3E-03	1.5E-03	1.2E-03	1.0E-03			1.0E-03	1.0E-03	2.4E+00
1979	7.4E+08	1.5E-04	1.9E-04	1.0E-03	5.2E-04	7.4E-04		3.0E-04	3.7E-04	2.6E-04	3.7E-04	3.3E-04			1.0E-03	1.0E-03	2.4E+00
1980	3.7E+07	2.2E-04	2.2E-04	7.8E-04	3.3E-04	5.2E-04		3.3E-04	3.3E-04	3.3E-04	3.3E-04	3.3E-04			7.8E-04	7.8E-04	1.9E+00
1981	1.9E+09	1.1E-04	1.9E-04	3.0E-04	3.0E-04	3.3E-04	3.3E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	3.3E-04	1.5E-04		3.0E-04	3.0E-04	7.1E-01
1982	4.8E+09	1.1E-04	1.5E-04	4.1E-04	1.9E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04		4.1E-04	4.1E-04	9.8E-01
1983	1.7E+08	2.2E-04	3.0E-04	2.2E-04	2.6E-04	1.5E-04	1.5E-04	1.5E-04	1.1E-04	1.1E-04	1.9E-04	1.1E-04	1.5E-04		3.0E-04	3.0E-04	7.1E-01
1984	7.0E+07	3.0E-04	1.9E-04	4.8E-04	3.3E-04	1.9E-04	1.9E-04	1.9E-04	1.1E-04	1.1E-04	1.5E-04	1.1E-04	1.5E-04		4.8E-04	4.8E-04	1.2E+00
1985	1.4E+08	4.4E-04	2.2E-04	4.1E-04	4.8E-04	2.2E-04	1.5E-04	1.9E-04	4.1E-04	1.5E-04	1.5E-04	1.9E-04	1.9E-04		4.8E-04	4.8E-04	1.2E+00
1986	1.3E+07	2.6E-04	3.0E-04	3.0E-04	2.6E-04	2.6E-04	2.6E-04	2.6E-04	3.3E-04	1.5E-04	1.5E-04	2.2E-04	2.2E-04		3.0E-04	3.0E-04	7.1E-01
1987	1.1E+07	1.3E-04	1.3E-04	1.4E-04	1.3E-04	3.3E-04	2.6E-04	3.0E-04	1.9E-04	7.4E-05	1.9E-04	3.3E-04	3.7E-04		1.4E-04	1.4E-04	3.4E-01
1988	2.2E+06	1.6E-04	1.5E-04	1.5E-04	2.0E-04	3.3E-04	3.0E-04	3.0E-04	3.0E-04	2.6E-04	2.6E-04	2.6E-04	2.6E-04		2.0E-04	2.0E-04	4.7E-01
1989	1.1E+07	9.3E-05	1.1E-04	1.3E-04	8.9E-05	1.1E-04	1.7E-04	1.7E-04	1.3E-04	2.1E-04	1.0E-04	1.1E-04	1.3E-04		1.3E-04	1.3E-04	3.2E-01
1990	1.2E+06					1.1E-04	1.1E-04	2.3E-04	1.3E-04	1.6E-04	1.6E-04	1.4E-04	1.6E-04	1.2E-04		1.2E-04	3.0E-01
1991	2.5E+05	5.2E-05	9.3E-05	7.8E-05	4.8E-05	1.1E-04	1.0E-04	8.1E-05	1.2E-04	7.8E-05	1.2E-04	8.9E-05	1.2E-04		9.3E-05	9.3E-05	2.2E-01
1992	7.8E+07	5.6E-05	5.9E-05	4.8E-05	5.2E-05	9.6E-05	1.1E-04	1.2E-04	9.6E-05	1.2E-04	1.2E-04	1.1E-04	9.3E-05		5.9E-05	5.9E-05	1.4E-01
1993	1.2E+08					7.8E-05	4.1E-05	1.1E-04	4.8E-05	8.1E-05	4.8E-05	7.4E-05	4.8E-05	8.0E-05		8.0E-05	1.9E-01
1994		7.0E-05	1.3E-04	2.0E-04	9.3E-05	5.9E-05	4.4E-05	9.6E-05	5.6E-05	4.8E-05	4.8E-05	5.6E-05	7.4E-05		2.0E-04	2.0E-04	4.8E-01
1995																	
1996	1.1E+08					8.0E-05	9.6E-05	9.9E-05	8.5E-05	1.0E-04	7.7E-05	1.1E-04	1.0E-04				
1997																	
1998																	
1999																	
2000																	
2001																	